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An Evaluation of Crew Coordination and Performance During a Simulated UH-60 Helicopter Mission

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13. ABSTRACT (*Maximum 200 words*)

This research was designed to develop measures of aircrew coordination and mission effectiveness and to identify crew coordination training requirements for U.S. Army rotary-wing flight. Twenty crews planned and conducted a three-segment mission scenario in the UH-60 Flight Simulator that exposed crews to situations requiring coordination. Crew performance and communications were recorded during the final two scenario segments and three mission effectiveness measures were developed from the records: navigational accuracy, threat avoidance and evasion, and instrument approach. Communication rate, topics, functions, and content areas were analyzed as indexes of crew coordination. The results indicate that substantial differences in performance and communication profiles exist between crewmembers and across mission segments. There were significant relationships between crew coordination levels and performance on the three mission tasks. The results also indicate the need for aircrew coordination training for Army helicopter pilots. Five recommendations are made for an Army aircrew coordination training program.

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AN EVALUATION OF CREW COORDINATION AND PERFORMANCE DURING A SIMULATED UH-60 HELICOPTER MISSION

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ACT	Aircrew Coordination Training
ANOVA	Analysis of Variance
AQP	Advanced Qualification Program
ARIARDA	U.S. Army Research Institute Aviation Research and Development Activity
ASMIS	Army Safety Management Information System
ASRS	Aviation Safety Reporting System
CRM	Cockpit Resource Management
DIG	Digital Image Generation
EWO	Electronic Warfare Officer
FAA	Federal Aviation Administration
FARP	Forward Arming and Refueling Point
FLOT	Forward Line of Own Troops
HSD	Honestly Significant Difference
IMC	Instrument Meteorological Conditions
I/O	Instructor/Operator
IP	Instructor Pilot
LOFT	Line Oriented Flight Training
LOM	Locator Outer Marker
LZ	Landing Zone
MOST	Mission Oriented Simulator Training
NASA	National Aeronautics and Space Administration
NDB	Nondirectional Beacon
PC	Pilot in Command
PF	Pilot Flying
PI	Pilot
PNF	Pilot Not Flying
RL	Readiness Level
SOP	Standard Operating Procedure
UH60FS	UH-60 Flight Simulator
USASC	U.S. Army Safety Center
VMC	Visual Meteorological Conditions
WST	Weapon System Trainer

AN EVALUATION OF CREW COORDINATION AND PERFORMANCE DURING A SIMULATED UH-60 HELICOPTER MISSION

Introduction

As early as the 1950's, military researchers began to identify training content and techniques to enhance the coordinated performance of crews (Sherwood, 1953). More recently, the commercial transport aviation industry focused on increasing the safe and efficient operation of aircraft through training in cockpit resource management (CRM) (Jensen, 1987, 1989; Povenmire, 1989) and its cornerstone, crew coordination (Helmreich, 1986). CRM is defined as the utilization of information, equipment, and people as resources to achieve safe and efficient flight operations (Lauber, 1980). Conclusions drawn from research projects and from accident and incident data bases support the importance of effective CRM and the need for crew coordination training in aviation.

Definitions of Crew Coordination

Considerable research has addressed crew coordination issues and numerous training programs have focused on developing coordination among crewmembers. However, researchers have not agreed on an operational definition of crew coordination. In fact, many researchers have failed to define the phenomenon under investigation. For example, Hall and Rizzo (1975) stated that when coordination is viewed as a type of interactive behavior, it is difficult to describe, define, and measure. Turney, Cohen, and Greenberg (1981) **suggested that the context of the task itself may determine the operational definition of coordination (or other interactive skills). That is, as a team[1] or crew skill, coordination is defined by the nature and content of interactions specific to the team task. Siskel and Flexman (1962) described crew coordination only in global terms, stating that coordination involves the ability of crewmembers to work together, to anticipate each other's needs, to inspire confidence and mutual encouragement, and to communicate effectively.**

[1]When relevant research is cited from the team literature, team is used synonymously with crew. In other cases, the use of crew indicates individuals within an aircraft and team indicates individuals in more than one aircraft.

Other researchers have attempted to define crew coordination. Krumm (1960) viewed crew coordination from two perspectives: synchronization of action and response improvisation. Synchronization of action occurs when individuals involved in a common activity perform as needed during a particular time period. Responses made by the individuals are derived from standard operating procedures (SOPs) or other formal procedures. The presence of formal procedures structures the responses made by the crewmembers. Response improvisation occurs when individuals involved in a common activity perform effectively in problem solving situations that have no standard, predefined procedures. In this situation, crewmembers identify and discuss crew problems and objectives, are aware of others' responses, and respond in relation to the actions of the other crewmembers and to situational factors.

Most of the research, and therefore most of the definitions of crew coordination, has addressed commercial and military fixed wing flight, which is predominantly a high speed, high altitude regime. This flight regime primarily requires the synchronization of action, except during emergencies, takeoffs, landings, and military engagements.

In contrast, low altitude flight by rotary wing aircraft requires the frequent application of both crew synchronization and improvisation. Many events, such as encountering inadvertent instrument meteorological conditions (IMC), are governed by specific SOPs and involve a synchronization of actions. If the steps are completed as outlined in the instrument approach procedure, the outcome is generally assured. Responses may be practiced to provide an almost mechanistic reaction. Other events require response improvisation in which crewmembers must maintain an awareness of the ongoing situation and of the other's responses to the situation. For example, while attempting to evade a threat (e.g., an enemy radar-controlled antiaircraft weapon system), the pilot not flying (PNF) must remain oriented on the map by monitoring the direction the pilot flying (PF) is taking the aircraft. A more common example would be the coordination between crewmembers required to avoid striking an obstacle.

Low level flight in rotary wing aircraft requires rapid cognitive and psychomotor responses as the crewmembers interact with the environment and each other. In an accident analysis performed jointly by the U.S. Army Safety Center (USASC) and the U.S. Army Research Institute Aviation Research and Development Activity (ARIARDA), crew coordination was defined as the interaction between crewmembers (communications) and actions (sequence or timing) necessary for flight tasks to be performed efficiently,

effectively, and safely (Leedom, in preparation). This definition reflects both the types of crew coordination errors that were identified in the accident data base and the primary approaches that have been used to measure crew coordination.

Measurement Approaches

Two basic approaches have been used to measure crew coordination. In the first approach, trained check airmen rate crew performance on several dimensions of crew coordination. In the second approach, researchers analyze the communication between crewmembers to quantify ongoing coordination. The approaches have been used separately and in combination.

The first approach is exemplified by Helmreich and Wilhelm (1989), who developed a technique for trained evaluators to assess the resource management of crews in both aircraft and simulators. In their instrument, the Line Oriented Flight Training (LOFT) worksheet, check airmen use 5-point, interval rating scales to evaluate crew performance on 12 dimensions of crew coordination and on overall workload, overall technical proficiency, and overall crew effectiveness. This type of performance measurement instrument has been used extensively to evaluate crew performance during training (e.g., Taggart & Butler, 1989) and as a dependent measure in research (e.g., Simon, Risser, Pawlik, & Leedom, 1990).

Numerous researchers have used the second approach, investigation of the communication patterns of crews, to measure crew coordination and to identify methods of improving overall crew performance. Most often the research has examined the pattern and rate of communication as an index of coordination between crewmembers (e.g., Federman & Seigel, 1965; Foushee & Manos, 1981; Krumm & Farina, 1962). Although nonverbal communication does occur, verbal communication is assumed to be the primary measure of information transfer and coordination between crewmembers. Therefore, analyses of communication profiles and rates are thought to reveal continuous processes of coordination between crewmembers.

Improved crew coordination has been found to enhance both flight safety and mission effectiveness. These two performance aspects and other issues related to crew coordination are discussed in the following two subsections.

Crew Coordination and Flight Safety

Experimental evidence collected by Ruffell Smith (1979) first led to the identification of resource management behavior as an important variable in aviation safety and to the need for related behavioral skills training. In a full-mission simulation, Ruffell Smith found that a crew's effectiveness in identifying and utilizing the human and material resources available influenced how safely and effectively the crew handled problem situations.

A symposium was held in 1979 to encourage the awareness and improved use of crew resources by addressing human error as a cause of aviation accidents (Cooper, White, & Lauber, 1980). During the symposium, Lauber (1980) reported two analyses that demonstrated the importance of resource management in aviation accidents. First, a National Aeronautics and Space Administration (NASA) analysis of civilian jet transport accidents that occurred between 1968 and 1976 identified more than 60 accidents in which resource management problems played a significant role. Second, a search of the Aviation Safety Reporting System (ASRS) data base identified 670 jet transport incidents in which resource management was a contributing factor. Subsequent crew coordination research by government, industry, and academic sectors evolved directly from the symposium. Several recent reviews of this literature exist (e.g., Povenmire, 1989), but research relevant to the current project is summarized in the following paragraphs.

The importance of crew communication in flight safety was demonstrated by an analysis of incidents that occurred between May 1978 and August 1979. Billings and Reynard (1981) analyzed over 10,000 reports in NASA's ASRS data base to identify incidents that could be attributed to errors in information transfer. The most common errors occurred in verbal communication and included messages that were (a) not originated; (b) inaccurate; (c) incomplete, ambiguous, or garbled; (d) untimely; and (e) not received or misunderstood. These data reflect the deleterious effects that poor communication has on crew performance.

In addition to civilian research, a critical incident analysis of Army aviation accidents also indicated that poor crew coordination contributes to poor flight safety (Thornton & Zeller, 1991). Aviation accident reports contained in the Army Safety Management Information System (ASMIS) were analyzed to identify human error accidents in which crew coordination errors were a contributing factor. The analyses were limited to 384 rotary wing accidents occurring between

October 1983 and June 1989 that were attributable to on-board crew error. Eighty-four crew coordination errors were identified in 76 of the accidents.

Leedom (1990) identified four basic dimensions of crew coordination from the accident analysis: quality and frequency of information exchange, crew workload prioritization and distribution, cross monitoring of other crewmembers, and team relationships and crew climate. The quality and frequency of information exchange dimension consisted of three crew coordination errors: failure to announce a critical decision or action, failure to use positive communication techniques and standard terminology, and assumption of aircraft control without positive transfer. The crew workload prioritization and distribution dimension also consisted of three errors: failure to properly assign or direct clearing responsibilities, failure to properly direct assistance required inside the cockpit, and the inappropriate direction of a crewmember to a lower priority task. Two errors were included in the dimension of cross monitoring other crewmembers: failure to anticipate and offer assistance to the flying crewmember and failure to allow sufficient time to perform a directed action. The last dimension, team relationships and crew climate, consisted of one error: failure to challenge or correct a decision or action that placed the aircraft in a marginal or unauthorized flight condition. The errors in all four dimensions reflect the high level of behavioral and informational dependence between crewmembers for successful rotary wing flight.

Crew coordination errors most commonly occurred in the first two dimensions, with 41% in the quality and frequency of information dimension and 35% in the crew workload prioritization and distribution dimension. Approximately 12% of the errors occurred in each of the remaining two dimensions (Leedom, 1990).

In addition to accident and incident analyses, other evidence has demonstrated the relationship of flight safety and crew coordination. Foushee, Lauber, Baetge, and Acomb (1986) investigated crew coordination and performance in a full mission simulator scenario. Expert observers made ratings on several dimensions related to flight safety, such as planning and situational awareness, crew coordination, and communications. Errors were recorded and categorized as minor errors, moderately severe errors, and operationally significant errors. Crews who had recently flown together communicated more and made fewer moderate, operationally significant, and total safety errors than crews with no recent experience with each other.

Kanki, Lozito, and Foushee (1987) examined transcripts obtained from Foushee et al. (1986) to determine the interactive sequence of utterances between crewmembers rather than the specific content of their communication. The resulting communication profile was used to categorize the crews as having either homogeneous or heterogeneous patterns of communication. Crews who committed fewer errors used more standardized, homogeneous communication than the crews who committed more errors. The high error crews tended to have no convention for communicating. Kanki et al. concluded that standardized communication allows the prediction of the other crewmember's behavior, thus improving coordination.

In addition to the previous research, the Federal Aviation Administration (FAA) has recently instituted performance-based rather than time- and iteration-based training in the Advanced Qualification Program (AQP) for commercial carriers (Federal Register, 1990). The FAA specified in Special Federal Aviation Regulation 58 that commercial carriers who voluntarily participate in AQP must incorporate CRM principles into their crew training, although they may tailor their program to suit their own needs. Although the issuance of such a regulation does not provide direct evidence for the relationship of flight safety and crew coordination, it does indicate the importance the FAA gives to CRM training in relation to flight safety.

Crew Coordination and Mission Effectiveness

In addition to flight safety, crew coordination affects mission effectiveness. In the 1950s and 1960s, the U.S. Air Force conducted a series of studies investigating the effects of integrated crew training on mission performance. The research was conducted because the Air Force recognized that ground-based, individual flight trainers did not prepare the aviators to perform as crews. At that time, ground-based trainers only focused on developing the skills of the individual crewmembers; no trainers were available to teach crews how to coordinate their activities (Hood, 1960). Thus, the Air Force initiated a crew coordination training project that led to the development of an integrated B-52 crew trainer (Krumm, 1960).

In the integrated trainer, Krumm and Farina (1962) investigated the effects of training pilots and navigators together instead of training them individually by modifying the simulator training of students in the B-52 transition course. The students normally received nine training sessions in a simulator that trained only the individual

skills of each crewmember. The B-52 crewmembers did not train together and were not linked together by either instruments or an intercommunication system. A control group received the normal training. The crewmembers in the experimental group also received nine training sessions, but they were required to fly a full mission scenario as an integrated team with the crew stations linked together in three of the simulator training sessions. Krumm and Farina concluded that the integrated training improved the coordination between crewmembers during the simulator and the aircraft checkrides.

In addition, Krumm and Farina (1962) analyzed the pattern and rate of communication between crewmembers during selected segments of the training mission. The researchers used seven categories to classify the crew communication, such as provides information, orders course of action, and acknowledges receipt of messages. They found that crew coordination training affected the pattern of communication (i.e., the distribution of communications among categories) between crewmembers. In addition, the pattern was significantly related to objective measures of performance, including navigational and bombing accuracy. For example, the category of voluntary inputs differentiated between the crews who were the best and worst navigators. Crews who navigated more accurately also volunteered more information. The rate of communication between crewmembers was significantly related to flight line instructors' ratings of crew coordination and crew proficiency, but it was not significantly related to objective measures of performance (e.g., hours required to solo or bombing accuracy scores).

In a more recent experiment, Povenmire, Rockway, Bunecke, and Patton (1989) investigated the effects of crew coordination on mission effectiveness using a full mission scenario in the B-52 Weapon System Trainer (WST). Trained evaluators observed and rated each crew's coordination using the LOFT worksheet (Helmreich & Wilhelm, 1989). In addition, flight instructors provided a relative ranking of the crews' mission performance. The LOFT ratings were positively correlated with the rankings on both bombing and overall mission performance.

Povenmire et al. (1989) also tabulated and analyzed crew inquiries, advocacies, and conflicts. The analyses indicated that specific patterns of communication reflected good performance on specific mission tasks. For example, crews achieved higher scores when the electronic warfare officer (EWO) inquired more of the navigator. In addition, the frequency of voluntary confirmations of information was positively correlated with mission performance measures.

Povenmire et al. concluded that improved crew coordination enhances performance on mission tasks.

The previous research has shown that performance on mission tasks is affected by the ability of a crew to coordinate the activities of its individual members. As a result, crew coordination training programs have been developed to improve mission effectiveness and unit readiness in addition to flight safety.

Crew Coordination Training Programs

As the importance of improving and evaluating crew coordination skills has become apparent, both classroom and simulator training have been employed more frequently to improve CRM skills in commercial and military aviation. Classroom CRM training generally concentrates on dimensions thought to influence crew performance, such as interpersonal skills, leadership, communication, and stress management. Training programs may include classroom presentation, practice and feedback, and reinforcement of learning (Foushee, 1985). These programs typically attempt to create a collegial atmosphere in which crewmembers share problem solving and decision making responsibilities. Commercial aviation has developed LOFT to evaluate and improve CRM skills. A similar technique used by the Air Force, Mission Oriented Simulator Training (MOST), was designed to incorporate tasks and environments that are unique to missions.

Aircrew coordination training (ACT) and CRM programs differ substantially between the military services in content, the design and delivery of the program (i.e., training length and standards), the stage(s) of training in which ACT concepts are introduced, the interval of time between ACT and simulator practice, and the facilitator training guidelines. Except for anecdotal information, evaluations of ACT effectiveness are lacking for all the programs (Povenmire, 1989).

Problem

Because of the high level of behavioral and informational dependence that exists between crewmembers, successful rotary wing flight is dependent on crew coordination. For example, while navigating at low altitudes, both pilot crewmembers of an Army helicopter have distinctly different roles and must work cooperatively to

arrive at their destination. The PF maintains control of the aircraft and at the same time, focuses his visual attention outside the aircraft to maintain obstacle clearance. The PNF maintains awareness of the aircraft's position on its course by using a map and the aircraft navigation systems and by observing the terrain features. The PNF provides verbal directions to the PF about heading, altitude, airspeed, and flight path. Only the PNF knows the exact location of the aircraft with respect to the designated course and must provide information and verbal instructions to the PF to keep the aircraft on course. Conversely, the PF must ensure that the PNF is aware of relevant terrain features passing within the PF's field of view.

Most successful military operations involve the coordinated performance of individuals within teams (Hall & Rizzo, 1975). The interdependence of the crewmembers suggests that the development of crewmembers' abilities to coordinate their activities to perform their missions safely and effectively is a critical objective of crew training. The Army philosophy of training has traditionally viewed aviators as individuals, rather than crews. Aviators are trained and evaluated as individuals throughout their careers. Little emphasis is placed on integrating the individuals into crews who maintain their individual proficiency, yet function as an effective unit.

Unfortunately, analysis of the USASC's accident data base indicates that ineffective crew coordination degrades both flight safety and mission performance in the Army. In addition, previous research and anecdotal reports from field units provide evidence that poor crew coordination degrades mission effectiveness.

At present, little is known about crew coordination in rotary wing aircraft. Current Army aviation training manuals include some references to crew coordination issues, but there is no empirical basis for including these topics. The majority of crew coordination research has investigated fixed wing aircraft flying air transport missions at high altitudes. Little research has investigated crew coordination within the Army's flight environment and tactical mission. There is concern that, because of its unique flight regime, the Army's crew coordination requirements may differ from those of the air transport mission.

For example, Army rotary wing aircraft frequently fly in extremely lethal environments at altitudes below 100 ft above ground level. These factors reduce the time that a crew has to respond to any situation. In cases of extreme time

stress, it may be more effective to develop procedures for coordination rather than a climate for coordination. Thus, crew coordination training conducted for the air transport mission may be relevant but not sufficient for Army aviation.

Research Objectives

Because of the relationships between crew coordination and mission safety and effectiveness, the Army has proposed to incorporate a crew coordination training program into its institutional and operational unit flight training. The program is to be based on the crew coordination requirements specific to the Army's aircraft, flight regime, and mission.

The present research was undertaken to develop a basic understanding of crew interaction in the helicopter under strenuous mission requirements and to provide the information needed to guide the development of a crew coordination training program. The UH-60 helicopter was selected as the research testbed because previous research has indicated that it has the largest problem with aircrew coordination errors (Thornton & Zeller, 1991). The research concentrates on the effects of crew coordination on mission effectiveness for two reasons. First, aviation accidents and incidents are relatively rare occurrences and the precipitating and causal factors leading to them are highly complex. In contrast, mission task performance can be observed and evaluated during each flight. Objective and reliable mission performance measures are, therefore, more useful dependent variables than safety measures for evaluating crew coordination effects. In addition, improved crew coordination can potentially enhance performance on all Army aviation missions, not just those that involve safety accidents or incidents.

Thus, the objectives of this research are as follows:

- determine the relationship between crew communication and mission requirements,
- identify reliable and objective performance measures for crew tasks,
- determine the relationships between intracrew communication and performance on crew tasks,
- identify communication profiles that are related to good crew performance, and
- propose training objectives for a crew coordination training program.

Method

This research was designed to obtain information about crew coordination in rotary wing aircraft and to identify objectives for crew coordination training programs. Because of the limited information available about rotary wing crew coordination, an observational rather than an experimental approach was adopted for this research. That is, all the crews were observed performing a typical tactical mission in a UH-60 Flight Simulator (UH60FS) without experimental manipulations. In addition to gathering information about crew coordination in rotary wing aircraft, the research was designed to be a testbed for developing procedures and performance measures to be used in subsequent investigations of crew coordination.

Overview

Twenty UH-60 crews planned and conducted a typical tactical mission in the UH60FS. Each crew was given a mission briefing that provided all the information necessary to conduct the mission satisfactorily and allowed 2 hours to conduct their premission planning. The crew then entered the UH60FS and conducted the mission. Audio/video recordings were made of the crew from the moment they entered the UH60FS until they departed. After completing the mission, the crew was debriefed and critiqued by the instructor pilot (IP) and the simulator operator.

Personnel

Aircrews

A UH-60 crew normally has three members: a pilot-in command (PC), a pilot (PI), and a crew chief. The crew chief is not required to participate in most of the flying tasks and the UH60FS does not provide a crew station for the crew chief; therefore, only the PC and PI were included in this research. When required, the simulator instructor/operator (I/O) played the role of the crew chief.

The commander of an operational aviation brigade located in the continental United States selected 40 aviators who were qualified and current in the UH-60 aircraft to participate in this research. The commander's selections were based primarily on the aviators' previous flight experience and training. All the aviators had achieved Readiness Level (RL) 1 in their training, except one who was

relatively new to the unit and had not completed progression training through all the unit mission tasks. In addition, 31 aviators were qualified to perform duties as flight lead for multiaircraft operations. After being briefed about the nature of the research and their participation, all the aviators signed informed consent statements.

The unit operations officer formed 20 flight crews from the 40 aviators. The operations officer assigned the crews and crew duties (PC or PI) on the same criteria used to assign crews for normal training missions in the aircraft. The criteria included flight experience, mission and training requirements, and the strengths and weaknesses of the individual aviators. If both aviators in a crew were qualified to perform PC duties, the crew decided who would function as the PC and PI.

Flight experience varied across the aviators designated as PC and PI (see Table 1). Although the PCs had a higher mean total flight time, UH-60 flight time, and flight time in the past 6 months (M = 1129.2, 656.8, 130.8, respectively) than the PIs (M = 866.0, 537.8, 112.5, respectively), the differences were not statistically significant. The PCs' time in unit was significantly greater than the PIs, $t(37) = 2.7$, $p < .01$. All of the PCs and 11 of the PIs were flight lead qualified.

Table 1

Experience Levels for Pilot in Command (PC) and Pilot (PI) Aviators

	PC (n = 20)		PI (n = 20)	
Experience	Median	Range	Median	Range
Total flight hours	975	549 - 2500	575	190 - 2000
UH-60 flight hours	615	200 - 1200	400	90 - 2000
Flight hours in past 6 months	150	40 - 200	120	35 - 150
Months in unit	18	6 - 33	7	1 - 33

Instructor/Operators

Three I/Os who were assigned to a UH-60 flight simulator facility participated in this research. Each was an experienced UH60FS operator with prior experience in the UH-60 helicopter. The I/Os received 8 hours of classroom instruction regarding crew coordination and assisted the researchers in the technical aspects of developing the scenario.

Instructor Pilots

Three UH-60 IPs from the same battalions as the UH-60 pilots participated in this research project. Before the data collection began, the IPs received the same training as the I/Os and assisted in developing the mission scenario and the measurement instruments and procedures.

Equipment

Flight Simulator

A production model of the UH60FS was used to conduct the tactical mission scenario. The UH60FS is a single cockpit mounted on a six-degree-of-freedom motion platform. The forward portion of the cockpit is physically and functionally identical to the PC and PI crew stations in the UH-60A aircraft. The I/O station is located directly behind the PI's crew station (see Figure 1). In addition, there is an observer station located behind the copilot station.

External visual scenes are produced by a digital image generation (DIG) system and displayed to the crewmembers on three channels, one forward and one on each side. The DIG data base replicates a generic gaming area of approximately 80 km x 100 km. In addition to terrain and cultural features, the DIG system provides a capability for the crew to interact with threat weapon systems. The UH60FS is fully described in the Operator's Manual for the UH-60 Flight Simulator (Department of the Army, 1987).

Audio/Video Recording Equipment

Four remote-head, charge-coupled device cameras manufactured by Cohu, Incorporated (San Diego, California) were used to record the crews during the mission scenario. The cameras provide high quality monochrome images in low

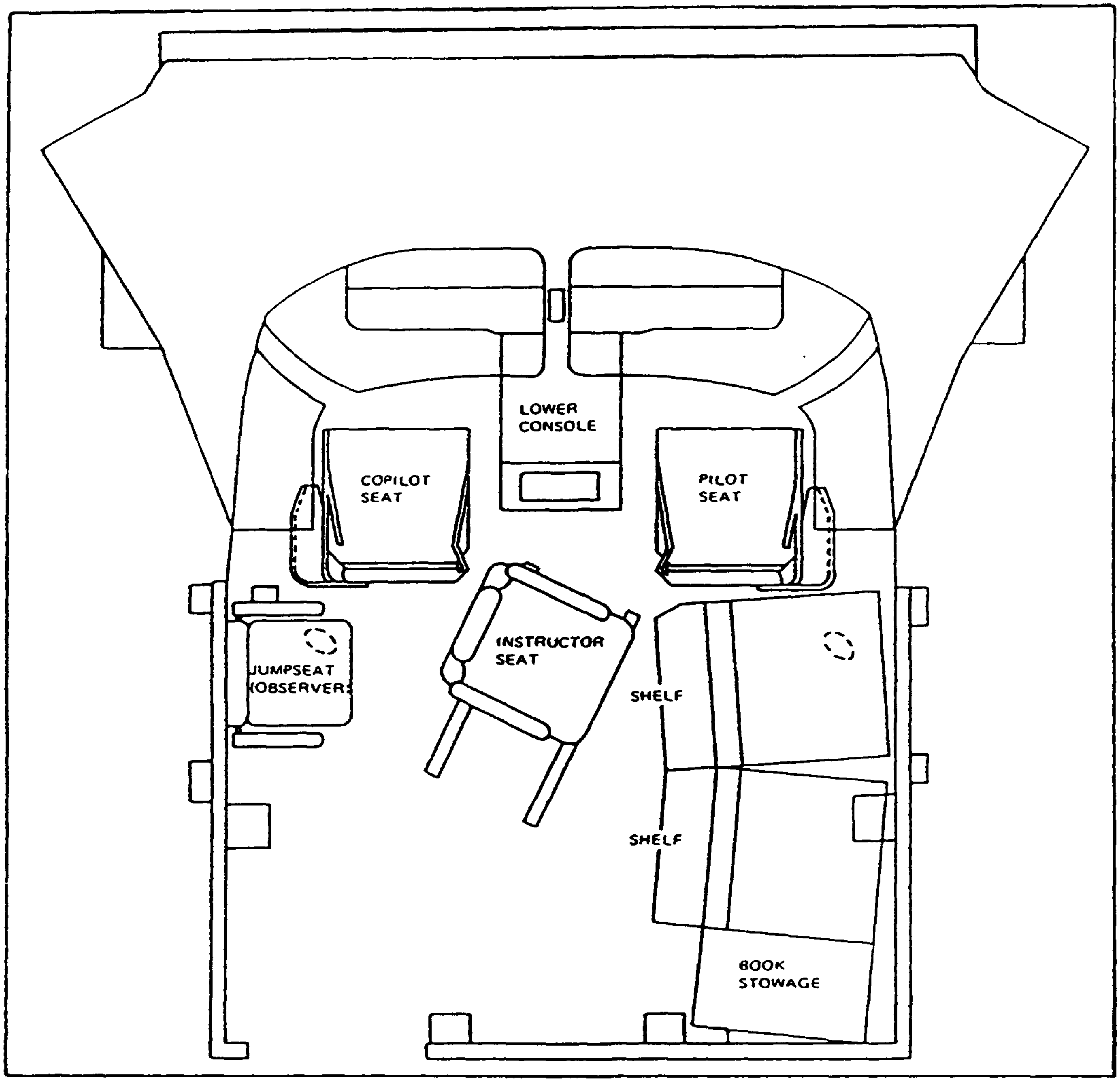

Figure 1. Diagram of the UH-60 Flight Simulator.

light levels. Three cameras were positioned inside the UH60FS to provide three distinct views of the crew: the face of the PC, the face of the PI, and the center console of the crew station, including the backs of both crewmembers. The fourth camera recorded a computer monitor view of the forward channel of the DIG visual scene. All four cameras were connected to an audio/video recorder located in an adjacent room. In addition, all sounds and utterances transmitted on the UH60FS intercommunication system were recorded for subsequent transcription.

Simulated Mission Scenario

Several criteria were used to develop the mission scenario for this research project. First, the scenario was designed to present events that were likely to be affected by crew coordination (e.g., Thornton & Zeller, 1991). Second, the scenario was designed to be consistent with the unit's operational mission. Third, the scenario was designed to evaluate the crews' performance on tasks for which they had been trained and not to evaluate them in novel situations. Fourth, the scenario only included tasks that all the aviators were likely to perform satisfactorily.

Mission Briefing Materials

A standard mission briefing (see Appendix A) containing the requirements and details of the mission was presented to each crew before the simulator session. The briefing packet followed the format specified by the unit's SOP. The materials included a tactical navigation map that presented accurate terrain and cultural information and the approximate location and composition of threat defenses.

Scenario Composition

The scenario was divided into three segments that were conducted contiguously: a single aircraft resupply mission carrying an external load, a multiaircraft troop insertion across the forward line of own troops (FLOT), and, following an inadvertent entry into instrument meteorological conditions (IMC), a nonprecision instrument approach to an airfield (see Figure 2).

The first segment, resupply of the forward arming and refueling point (FARP), was designed to give the crew

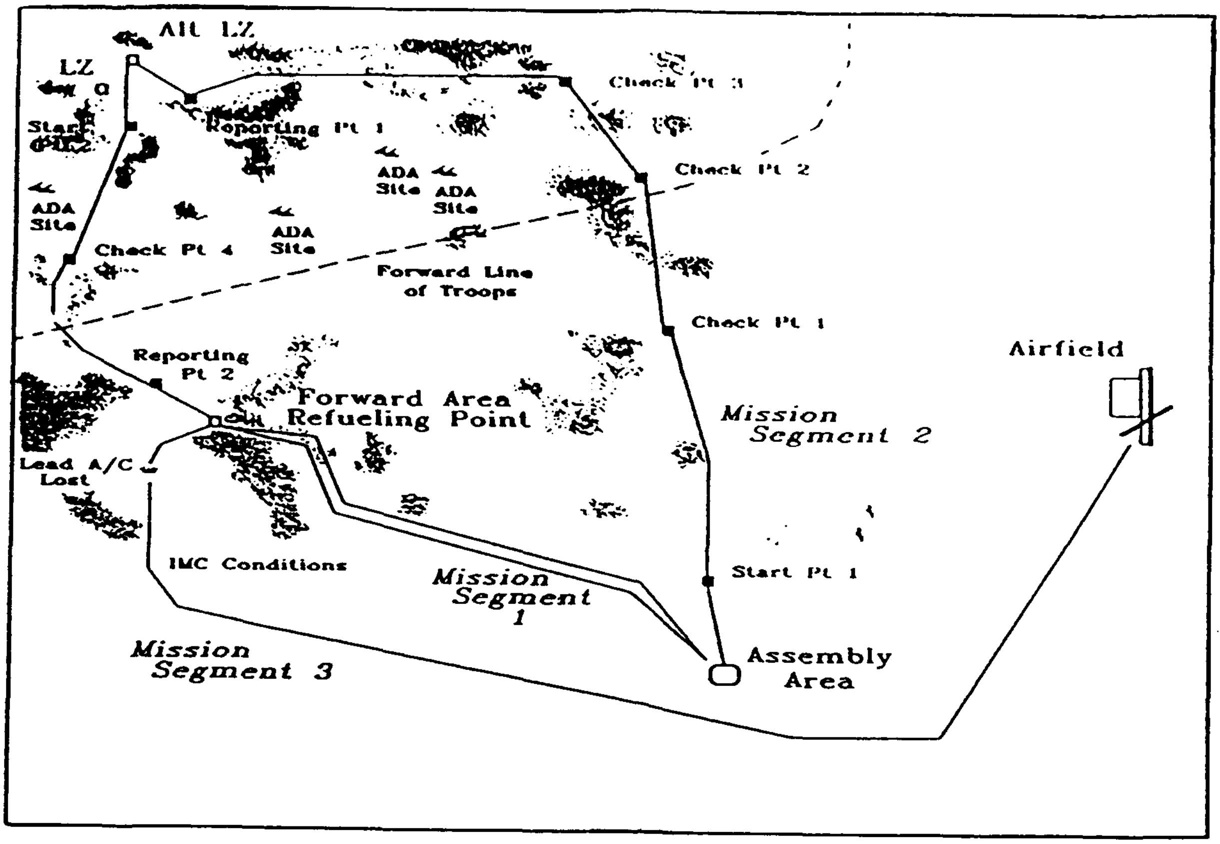

Figure 2. Schematic diagram of the scenario.

practice in flying the UH60FS. Thus, no time, weather, or threat constraints were imposed on the crew in this segment. During the segment, the crew was required to carry an external load of fuel from an assembly area to the FARP and then to return to the assembly area. Each crew planned their own route of flight, airspeeds, and altitudes.

During the second segment, troop insertion, the crew was required to depart the assembly area as lead aircraft in a flight of five UH-60 aircraft, to insert infantry troops across the FLOT, and to return to the FARP established in the first segment. The crew was required to deliver the troops to the landing zone at a prescribed time. In addition, the crew had to evade several enemy antiaircraft weapon systems situated near the route of flight. The planned route of flight for this entire segment was standardized for all crews and designated during the mission briefing. The route covered approximately 40 km.

During the third segment, instrument approach, the crew was required to fly from the FARP to the assembly area. During the final segment, however, the crew encountered deteriorating weather conditions that forced them to transition to instrument flight and to perform a nonprecision instrument approach to an airfield using a nondirectional beacon (NDB).

Simulator Session Procedures

All data were collected over a period of 2 weeks. Two crews were observed each day, one crew during a morning session and one during an afternoon session. The aviators were identified and assigned to crews at least 24 hours before the scheduled session.

Upon arrival at the test site, each crew received the mission briefing and conducted their premission planning. Following the planning session, one of the unit IPs reviewed the aircrew's planning for accuracy. Two hours were provided for planning and review. Immediately after the review, the crew entered the UH60FS and conducted the mission. The crews decided which aviator would fly the aircraft and which would perform the duties of the nonflying pilot. Furthermore, the aviators were allowed to switch the controls during the flight at their discretion.

The I/O manipulated the simulator controls and played other roles in the scenario by making scripted radio calls. The roles played by the I/O included the crew chief, other aircraft in the flight, approach control, and the tactical operations center. In addition, the IP occupied the observer station in the UH60FS to observe the crew and to assist the I/O during radio calls. Following completion of the mission in the UH60FS, the IP and I/O provided feedback to the crew about their performance.

Mission Effectiveness Measures

The measures of performance on crew tasks and crew coordination were compiled by reviewing the recordings of the 20 crews while they performed the troop insertion and instrument flight segments of the UH60FS scenario. Separate measures of crew performance were obtained for three types of crew tasks: terrain flight navigation, threat encounters, and NDB approach. The three crew tasks were selected for two reasons. First, each task is critical to the successful completion of the mission. Therefore, crew performance on

each task is considered to be a measure of overall mission effectiveness. Second, the crew tasks are sensitive to time pressure and require considerable interaction between the two crewmembers. Thus, they were expected to be sensitive to differences in crew coordination.

Communication analyses were used as measures of crew coordination during the mission scenario. Communication data were compiled by transcribing all verbal utterances transmitted over the intercommunication system during the two segments.

Terrain Flight Navigational Measures

During the troop insertion segment, the crews were required to conduct terrain flight navigation over a specified route of approximately 40 km. Terrain flight navigation is a crew task that is normally conducted at altitudes of 200 ft or less above the highest obstacle. As discussed in the Introduction section, terrain flight requires that the PF control the aircraft and maintain obstacle clearance. The PNF must maintain awareness of the aircraft's position and provide verbal directions to the PF. The Army performance standard for terrain flight navigation is for the crew to know their location within 500 m (Department of the Army, 1988).

Three primary and two secondary measures were used to evaluate terrain flight navigational performance during the troop insertion segment. The primary measures were assessed over the entire segment for all the crews. The length of flight is the elapsed time from takeoff from the assembly area until final landing in the FARP. The number of deviations is the number of times each crew committed a navigational error by unintentionally deviating from the route by at least 500 m. The percentage of time off course was calculated for each crew by dividing the total time a crew spent off course by that crew's length of flight.

The secondary measures were analyzed for coordination errors as they occurred for each crew. First, crew coordination errors were analyzed if the crew failed to make or to follow the instructions received from a required radio call prior to arrival at the troop insertion landing zone (LZ). Second, crew coordination errors were analyzed if the crew hit an obstacle or the ground during the terrain flight.

To obtain the five measures, the researchers reviewed the audio/video tapes for each crew to determine the length

of the flight segment and the flight track and to identify occurrences of the secondary measures. Course deviations were determined by comparing the flight track to a 1000 m wide corridor superimposed over the specified route of flight. The researchers recorded both the number of times each crew deviated from the assigned corridor and the length of time they remained outside the corridor. To determine the causes of navigational errors, two researchers independently reviewed the section of tape preceding each error and then collaborated to reconcile differences in their attributions.

Threat Evasion Measures

During the troop insertion segment, encounters with several antiaircraft weapon systems were possible. The type, location, and activity levels of the threats were standardized across all crews. If a crew entered the effective range of a threat weapon system and established intervisibility with the threat, an aural warning in the UH60FS was activated. Variations in the tone of the warning indicated the activity mode of the threat weapon system: search, track, or missile. The three modes represent increasing levels of danger to the crew.

Threat evasion is considered a crew task because the crewmembers have a common goal to avoid enemy activity and each crewmember has clearly defined and complementary tasks to perform. In most cases, threat evasion takes immediate priority over most other tasks. Both crewmembers are alerted to the danger by the aural warning. However, the PF must maintain his attention outside the aircraft for obstacle clearance and fly as low as possible to utilize available terrain features to evade the threat. The PNF must monitor the indicator inside the aircraft and direct the PF away from the threat. In addition, the PNF must remain aware of the crew's position on the map and resume normal navigation after the crew has evaded the threat.

The researchers reviewed the tapes of each crew and recorded the number and duration of warning system activations that exceeded the search mode. The number of activations indicates the success of threat avoidance. The duration indicates the success of threat evasion.

Nonprecision Instrument Approach Measures

Following the troop insertion segment, each crew was required to perform a flight segment that ended with a

nonprecision instrument approach to an airfield using an NDB. An instrument approach is a crew task that transitions the aircraft from IMC to visual meteorological conditions (VMC) for landing. The PF must monitor the navigation instruments and maintain control of the aircraft. The PNF must monitor the system's status instruments, make radio calls, and ensure the PF adheres to the published approach procedures and directions given by the air traffic controller.

A researcher reviewed the recordings of each crew's performance and used a checklist (see Figure 3) to indicate whether the crew performed the procedural tasks required to complete the NDB approach successfully.

The researchers identified four overall aspects of the procedures that are critical for a properly executed NDB approach:

- both crewmembers reviewing the approach plate and discussing the essential elements of the published approach prior to its execution,
- successfully tracking all of the headings established for the approach,
- maintaining all altitudes established for the approach, and
- properly timing the inbound portion of the approach.

To derive an overall measure of performance for the instrument segment, the researchers awarded one point for each aspect that the crew successfully accomplished.

Crew Coordination Measures

Crew communication was used as an index of crew coordination. The audio recordings of each crew were transcribed verbatim. Each crew's verbalizations were decomposed into message units that were defined as a word, phrase, or sentence expressing no more than one complete thought. Two researchers, working independently, coded each message unit on three dimensions: general topic, function, and content. Then the two researchers reviewed the classifications for each message unit and reconciled any coding differences.

The first dimension divided communication into five topics: navigation, mission, threat, instrument flight, and other (see Table 2). The topics were based on general areas of concern during a typical mission.

INSTRUMENT APPROACH

Crew Number: __________ Reviewed Approach Plate: PI PC

Procedure	Yes	No	Unk.	Flying
Cross LOM at assigned alt.	☐	☐	☐	PI PC
Turn to intercept 019° or to 049° for teardrop entry	☐	☐	☐	PI PC
Start clock when abeam LOM	☐	☐	☐	
Conduct procedure turn	☐	☐	☐	PI PC
Intercept and track 199° to LOM	☐	☐	☐	PI PC
Remain within 10 NM of LOM	☐	☐	☐	
Descend to 2100 feet	☐	☐	☐	
Call controller as directed	☐	☐	☐	
Cross LOM at 2100 ft, tracking 199°	☐	☐	☐	PI PC
Start clock at LOM inbound	☐	☐	☐	
Descend to 1200 ft	☐	☐	☐	
Breakout/flying after breakout	☐	☐	☐	PI PC
Remain VMC and track 199°	☐	☐	☐	
Align to locate runway	☐	☐	☐	

Note. PI = pilot; PC = pilot in command; LOM = locator outer marker; Unk. = unknown; alt. = altitude; NM = nautical miles; VMC = visual meteorological conditions.

Figure 3. Checklist of instrument approach procedures.

Table 2

Message Unit Topic Categories and Definitions

	Topic	Definition
1.	Navigation	A message unit concerning the low level navigation of the aircraft
2.	Mission	A message unit concerning tactical mission objectives
3.	Threat	A message unit concerning threat weapon systems
4.	Instrument flight	A message unit concerning instrument flight procedures
5.	Other	A message unit that does not fit any of the other topics

Each message unit was then categorized into 1 of 13 communication functions (see Table 3). Functions 1 - 5 and 13 were based on categories used in previous research (e.g., Bales, 1950; Foushee, Lauber, Baetge, & Acomb, 1986; Krumm & Farina, 1962). Four functions (6, 9, 10, and 11) were added to provide information about communications that might be relevant to the success of the mission. Functions 7, 8, and 12 were added to describe communication with sources other than the PI and PC (e.g., the crew chief and other aircraft).

Finally, Functions 1 through 8 were divided into content areas (see Table 4; full definitions of the content of message units are presented in Appendix B). The content areas were designed to provide more information about the subject of each message unit.

After all the utterances had been categorized on the three dimensions, the number of message units that performed specific communication functions and that related to specific content were counted. The frequency data were converted to percentages of total communication for each crew during each segment. That is, for each crew, the number of communications for each function and for each content area was divided by the total number of communications emitted by that crew during each mission segment. The communication percentages were also calculated separately for each PF and PNF.

Table 3

Message Unit Function Categories and Definitions

	Function	Definition
1.	Inquiry	An interrogative message unit asked by one crewmember and directed to the other crewmember
2.	Command	An imperative message unit issued by one crewmember that directs the other crewmember to perform a task
3.	Declarative	A message unit proclaiming a fact or belief relating to the task
4.	Response to inquiry	A message unit in response to an inquiry by the other crewmember
5.	Acknowledgement	A message unit indicating that a command or a declarative statement was received
6.	Aircraft clearance	A message unit that directs the other crewmember to determine if the aircraft is clear of obstacles or informs the other crewmember of aircraft clearance
7.	Radio transmission	A message unit transmitted over a radio, except Function 8
8.	Navigational assistance	A message unit that acknowledges that the crew is disoriented, requests navigational assistance from someone external to the crew, or that provides assistance by someone external to the crew
9.	Flight review	A message unit referring to previous events in the flight
10.	Correct current error	A message unit that rectifies incorrect actions or information
11.	Feedback	A message unit that indicates the appropriateness of an action by the other crewmember
12.	Directed toward crew chief	A message unit directed toward the crew chief, except a request for clearance
13.	Uncodable or irrelevant	A message unit that is irrelevant to the mission, does not fit into any other category, or is an incomplete utterance

Table 4

Message Unit Content Categories for Functions 1 - 8

Function	Content
1. Inquiry	System status
	Initiate checklist
	Heading or direction
	Terrain features
	Instrument reading
	Aircraft position
	Other
2. Command	Flight systems
	Initiate checklist
	Bounded heading or direction
	Altitude
	Airspeed
	Unbounded turn
	Stop turn
	Anticipatory
	Other
3. Declarative	Instrument reading
	Terrain identification
	Anticipatory
	Checklist response
	Aircraft flight path
	Aircraft position/flight status
	Aviator intent
	System status
	Derogatory toward simulator
	Direction of aviator attention
	Other
4. Response to inquiry	Serves as a command
	Confirm/affirm
	Negative/corrective
	Other
5. Acknowledgment	Command
	Declarative
6. Clearance	Request/direct aircraft clearance
	Clears aircraft
7. Radio transmission	Aircraft position
	Formation control
	Operations control
	Approach control
8. Navigational assistance	Request assistance
	Provide assistance

Results and Discussion

The first two parts of this section present descriptive information about the three types of crew performance measures and about the crew communication measures. The third part examines the relationships between crew communication and mission performance.

Mission Effectiveness

Mission effectiveness measures were obtained for three crew tasks: terrain flight navigation and threat encounters during the troop insertion segment and nonprecision instrument approach during the instrument flight segment. The troop insertion segment of one videotape was damaged. Therefore, navigation and threat encounter performance were analyzed for only 19 of the 20 crews. Members of two crews experienced simulator discomfort following the troop insertion segment and did not complete the instrument flight segment. Therefore, performance during the instrument flight segment was analyzed for only 18 crews.

Terrain Flight Navigation

The 19 crews varied considerably on the three primary measures during the troop insertion segment and in making the required radio call. There was only one instance of a ground impact that was related to crew coordination.

Length of flight. The length of flight ranged from 23.2 min to 42.0 min; the mean length of flight was 30.3 min. The differences in flight time were primarily related to the airspeeds flown, the accuracy of navigation, and the length of time that was required to become reoriented after committing a navigational error. Airspeeds are governed by SOPs, but the crews may adjust their airspeed within guidelines at their discretion. The more navigational errors that occurred, the longer the flight time. Finally, the time needed to reorient was affected by individual navigational proficiency, presence of threat activity while off course, and awareness of navigational errors.

The crews were required to deliver the troops to the designated LZ at a specified time. However, simulator problems (e.g., DIG failures) interfered with the continuity of the flight and prevented the accurate assessment of performance on this measure.

Deviations from course. The 19 crews committed 38 deviations of at least 500 m from the designated route. The number of deviations ranged from 0 (3 crews) to 3 (3 crews) with a mean of 1.5 per crew. Six deviations were attributed to actions the crew took to avoid detection by a threat and three deviations were attributed to actions planned by the crew to use terrain features for masking or navigation. These nine deviations from course were not considered to be navigational errors because the crews intentionally deviated from the course and were aware of their location at all times. Each of these crews returned to course as soon as the maneuver was completed.

Navigational errors by individual crewmembers were responsible for 24 deviations from course. That is, the deviations were attributed to skill deficiencies of an individual crewmember rather than to crew coordination. Most of the individual navigational errors occurred in (a) basic map reading, (b) associating aircraft heading and position, (c) interpreting terrain features, and (d) operating the Doppler Navigation System.

The five remaining deviations from course were attributed to errors in crew coordination similar to those contributing to Army aviation accidents (Thornton & Zeller, 1991). The failure of the two crewmembers to coordinate led directly to the deviations from course. Two categories of errors from the crew coordination dimension of quality and frequency of information exchange were identified: lack of positive communication technique and failure to announce critical decisions or actions.

Positive communication errors occur when either pilot issues an instruction or transmits other information but fails to verify that the other pilot complies with the instruction or receives the information. In one instance, for example, the PNF directed the PF to turn right. As he issued the instruction, the PNF began looking at his map and no longer attended to what the PF was doing. The PF did not comply with the turn instruction and the aircraft proceeded off course without the knowledge of either pilot. The PNF failed to verify that the PF heard and complied with the turn instruction.

Announcement errors occur when one crewmember fails to notify the other crewmember of an action being taken or of information important to the other crewmember's assigned task. For example, the PF of one crew made an uncommanded left turn and failed to notify the PNF that he was initiating

a turn. At the time, the PNF was distracted by a minor problem and failed to notice the turn. Therefore, the aircraft proceeded on a heading that resulted in a deviation from course and the crew became lost.

<u>Percentage of time off course</u>. Not only could some crews not track the course, but they also had difficulty relocating the course ($\underline{M}$ = 27% time off course). Three crews had no deviations from course. Four crews were off course between 6 and 16% of the time, five crews were off course between 22 and 34% of the time, and the remaining seven crews were off course between 37% and 76% of the time during the troop insertion segment.

Observations made from the videotapes indicated that crews frequently did not decrease their speed after becoming aware of a navigational error. In these cases, the PNFs should have directed the PFs to slow the aircraft to allow the PNF more time to reorient on the map. In one case, the PF recommended that they return to a known terrain feature on course, which could have been easily accomplished. The PF's lack of assertiveness in pursuing the recommendation allowed the crew to deviate farther off course.

<u>Required radio call</u>. Before arriving at the LZ to insert the troops, the crews were required to make a radio call to inform ground control of their imminent arrival at the release point. The call was important because ground control used a code word (Joker) to indicate the LZ had been changed to an alternate location. Seven of 19 crews landed at the original but incorrect LZ. Of these seven, four crews did not make the required radio call that would have instructed them to land in the alternate LZ. A fifth crew made the call on the wrong frequency and never received the change.

The remaining two crews received the alternate LZ code, yet still did not land in the correct LZ. Poor navigational skills, as determined by percentage of time off course, do not completely explain the crews' failure to land in the correct LZ. The first crew was never off course; the second spent 33% of the time off course. A more probable explanation of their failure to land in the correct LZ involves poor premission planning. It is likely that the two crews heard ground control reply "Joker," but did not remember that this meant that they should fly to the alternate LZ. Better planning accomplished by a thorough preview of the mission before takeoff might have alerted at least one crewmember to the meaning of the radio response.

The failures of the five crews to make the required call or to call on the correct frequency are examples of the criticality of adequate planning. An adequate awareness of the mission plan might have increased the probability that the radio call was made at the proper time and on the correct frequency so that a landing to the correct LZ could be executed.

Ground impact. Several of the crews hit the ground or an obstacle during the mission, but only one of the impacts was related to crew coordination. In that situation, an impact with the ground was related to a crew coordination error of prioritization and distribution that was similar to errors found in the ASMIS analysis (Leedom, 1990). The PNF directed the PF to check the time on the Doppler Navigation System. As the PF looked inside the cockpit, forward cyclic was inadvertently applied and the aircraft nosed over, striking the rising terrain. This error occurred because a crewmember was directed to a lower priority task and neglected to monitor a more important task.

Threat Encounters

Two measures were used to evaluate threat encounter performance. The number of encounters evaluated the crew's performance in avoiding threats. The duration of the threats represented the crew's performance in evading the threat once it was encountered.

Number of encounters. All the crews encountered at least one antiaircraft threat and most crews experienced multiple encounters (M = 4.2). The number of encounters varied between 1 and 10. One factor in the number of threats encountered was whether the crews remained on course. The route of flight was planned so that threat systems were not located directly on the route but were displaced by several kilometers. When on course, the aircraft was within the range and line of sight of only one threat. Thus, crews who were not flying on the course were more likely to encounter threats. Conversely, if a crew recognized they were not on course, their disorientation probably affected their response to the threat.

Duration of encounters. The success of the crews in evading the threat varied as did their success in avoiding the threat. The total duration of threat encounters varied between 5 and 129 s with a mean of 54.3 s. The average duration of encounters ranged from 5 to 23 s with a mean of 12.0 s. The longest duration of an encounter for each crew

ranged from 5 - 56 s, with a mean of 20.5 s. One crew encountered three threats, but the longest encounter lasted only 8 s. In contrast, another crew encountered only one threat, but it lasted for 20 s. Increasing the length of any threat engagement increases the probability that the threat will attack and possibly destroy the aircraft. The longest encounter is probably more indicative of the danger to the crew than the number of encounters or the total duration of the encounters.

Nonprecision Instrument Approach

Eighteen of the 20 crews completed the instrument flight segment of the mission. Five crews satisfactorily performed each of the four critical aspects of the NDB approach. Four additional crews failed only to track the appropriate outbound heading during the procedure turn. The remaining 9 crews made errors involving more than one critical aspect. Of the 13 crews who made at least one error, 12 failed to track the appropriate headings, 6 failed to review the approach plate adequately prior to executing the approach, 5 failed to maintain the appropriate altitudes, and 2 failed to time the final inbound leg of the approach.

Of the 12 crews in which both crewmembers reviewed the approach plate, 10 completed the instrument segment safely. Of the 6 crews in which both crewmembers did not review the plate, none was able to perform more than two of the critical aspects satisfactorily. Thus, planning and coordination by the crewmembers appears to promote successful mission effectiveness and flight safety. Typically, when both crewmembers reviewed the approach procedure and identified critical elements of the approach prior to initiating it, both crewmembers were able to contribute effectively in executing the approach.

Three crews each committed a critical error that endangered them during the instrument approach. One crew failed to maintain the appropriate ground track from the locator outer marker (LOM) inbound to the airfield and never found the runway. The second crew executed an approach on the reciprocal of the correct approach heading. Because of this error, the crew's descent was not guaranteed obstacle clearance and they did not locate the runway. The third crew descended to the minimum descent altitude too early in the approach. Although they did find the runway and did not strike any obstacles, they were at high risk of striking an obstacle.

A lack of assertiveness by a crewmember in clarifying information or commands perceived as inaccurate or inappropriate were observed in two crews who committed dangerous errors. In the crew who executed a reciprocal approach, the PNF questioned the PF's stated intention to turn to an incorrect heading but did not aggressively follow up by using the approach plate to confirm the heading or the PF's intentions. In the crew who descended too early, the PF questioned the inaccurate heading and descent altitude provided by the PNF. The PF made the turn to the wrong heading, and despite the PF's questioning of the altitude command, the PNF continued to direct an incorrect descent altitude.

Relationships Between Mission Effectiveness Measures

Pearson correlation coefficients were calculated to determine the relationships between the various measures of mission effectiveness (see Table 5). The measures of navigational accuracy were significantly related to each other. The number of deviations and percentage of time off course were most highly correlated. The two measures of threat encounter duration were positively correlated with each other, as was total duration and number of threat encounters. However, neither pair of variables in these correlations are statistically independent (e.g., the two duration variables are based on the same underlying behavior). The mean threat duration was not significantly correlated with the number of threat encounters, indicating that threat avoidance and threat evasion require different skills.

Each measure of threat encounter performance was significantly correlated with at least one measure of navigational accuracy. The number and total duration of threat encounters were positively correlated to the length of flight, mean duration of encounters was positively correlated to the percentage of time off course, and longest duration of threat encounters was positively correlated to both the percentage of time off course and the number of deviations.

These results indicate that crews who had trouble navigating also experienced difficulty evading the threat. However, in several cases, the crews were observed to ignore the threat while they were engaged in correcting their navigational errors. Because the crews received no penalty

Table 5

Intercorrelation Matrix of Mission Effectiveness Performance Measures

Performance measure	1	2	3	4	5	6	7	8
1. Length of flight	-							
2. Number of deviations	.56*	-						
3. % time off course	.55*	.68*	-					
4. Number of threat encounters	.48*	.12	.21	-				
5. Total duration of threat	.51*	.21	.39	.95*	-			
6. Mean threat duration	.14	.14	.55*	.30	.52*	-		
7. Longest threat duration	.36	.47*	.65*	.49*	.70*	.80*	-	
8. Instrument flight	.19	-.07	.00	-.08	-.11	.00	-.16	-

Note. n = 19 for measures 1 - 7 and n = 17 for measure 8.

*p < .05

for encountering threats and no reward (other than simulated survival) for evading them, the higher duration of threat encounters is probably related to the crews' giving navigation a higher priority than threat evasion.

To further test the relationships between navigational accuracy and the avoidance and evasion of threat, comparisons were made between crews who were good navigators and poor navigators for each measure of threat encounter performance. Crews were trichotimized at the largest breakpoints into good, moderate, and poor navigators based on the percentage of the troop insertion segment spent off course. Seven crews who spent between 0 and 16% of the segment off course were considered good navigators. The five crews who spent between 22 and 34% of the segment off course were considered moderate navigators. The seven crews who spent between 37 and 76% of the segment off course were considered poor navigators. A one-way analysis of variance (ANOVA) and Tukey Honestly Significant Difference (HSD) test (Tukey, 1953) identified differences between good (M = 5.7%), moderate (M = 28.1%), and poor (M = 47.6%) groups, $F(2, 16) = 32.53$, $p < .0001$.

Although all three groups were significantly different, only the extreme groups were considered in subsequent analyses because of the similarity in performance in the moderate group with the performance of some crews in the extreme groups (e.g., 34% off course in the moderate group versus 37% off course in the poor group).

The good navigators performed significantly better than the poor navigators in avoiding the threat and in evading the threat after it was encountered (see Table 6). When detected by a threat, the crew must first evade the threat and then resume efforts to reorient themselves. Good navigational crews were observed to fly lower and slower than poor navigational crews. Flying low reduced the good navigational crews' exposure to threat and flying slow assisted them in remaining oriented to the course.

The measure of instrument approach performance was not significantly related to any other mission effectiveness measure. Crew performance during the troop insertion segment was not a good predictor of crew performance during the instrument flight segment.

Table 6

Analysis of Threat Encounters for Good and Poor Navigators (n = 14)

	Good navigators (n = 7)		Poor navigators (n = 7)		
Threat measure	Mean	SD	Mean	SD	$t(13)$
Number of threat encounters	3.14	2.73	5.14	2.41	-1.45*
Total threat duration (s)	34.14	30.98	75.14	38.85	-2.18*
Mean threat duration (s)	10.79	4.74	14.50	4.41	-1.52*
Longest threat encounter (s)	14.14	6.87	29.86	15.09	-2.51*

*$p < .05$

Communication

Four aspects of communication were analyzed: rate, topic, function, and content. In analyzing crew communications, mixed design ANOVAs were conducted to determine if there were significant differences in the percentage of message units emitted between the mission segments, crewmembers, and communication topics, functions, and content areas. Communication topic, function, and content were within-group factors; crewmember (i.e., PF and PNF) and mission segment were between-group factors. All significant interactions were further analyzed with Tukey HSD tests.

Communication Rate

Communication rate is the mean number of message units emitted per minute of each segment. There was a significant interaction between the crewmembers and segments in the rate of communication, $F(1, 32) = 8.73$, $p < .01$. Although the verbal exchange of information occurred in both directions, PNFs communicated at a faster rate than the PFs during both segments and the crews communicated at a faster rate during the troop insertion segment than during the instrument flight segment (see Table 7). However, there was no difference in communication rate for the PNF during the instrument flight segment and the PF during the troop insertion segment.

Table 7

Rate of Message Units for Each Crewmember in Each Segment

	Troop insertion (n = 17)		Instrument flight (n = 17)	
Crew	PF	PNF	PF	PNF
Mean	5.6	9.4	3.7	5.4
SD	2.7	2.3	1.2	1.9
Range	9.1	7.8	4.4	7.5

Note. PF = pilot flying; PNF = pilot not flying.

These effects indicate that more verbal information was exchanged during the troop insertion segment than during the instrument flight segment, and that the PNF was primarily responsible for the increased verbal exchange. For example, during day terrain flight, the PNF provided information about upcoming terrain features that was not relevant during instrument flight.

Communication Topics

The mean percentage of message units in the five topics emitted by each crewmember during each mission segment is shown in Table 8. The three-way interaction was not significant, but there were two significant two-way interactions involving topics: Topics x Segment, $F(4,256) = 932.90$, $p < .0001$; and Topics x Crewmember, $F(4,256) = 11.06$, $p < .001$. More message units concerning navigational and tactical mission objectives occurred during the troop insertion segment; more message units concerning instrument procedures occurred during the instrument flight segment. The classification of message units reflects differences expected in communication for the two mission segments. More message units about other topics also occurred during the instrument flight segment; the higher rate of other messages

Table 8

Mean Percentage of Message Units for Each Topic in Each Mission Segment

	Troop insertion (n = 17)		Instrument flight (n = 17)	
Topic	PF	PNF	PF	PNF
Navigation	68.6	68.6	3.8	2.5
Mission	12.8	14.1	0.3	1.3
Threat	3.0	4.6	0.0	0.1
Instrument	0.0	0.0	66.1	74.5
Other	22.8	9.9	29.5	22.8

Note. PF = pilot flying; PNF = pilot not flying.

probably indicates that the coordination requirements during instrument flight are lower than during visual flight.

The Topics x Crewmember interaction supports this inference. There were no significant differences between crewmembers in the percentage of message units for navigational, mission, and threat topics. The PNF emitted significantly more instrument topic messages than the PF, reflecting his responsibility for providing the PF with instrument readings and for communicating with air traffic control. The PF emitted significantly more message units on other topics than the PNF, indicating that the PF is primarily a recipient rather than a generator of information during instrument flight.

Communication Functions

The mean percentages of message units for each of the 13 functions are presented in Table 9. The table shows the percentage of utterances for each crewmember during each segment. The majority of units were emitted in six function categories: inquiry, command, declarative, response to inquiry, acknowledgement, and radio transmission. The six functions accounted for 87.5% of the communications emitted during the troop insertion segment and 88.5% during the instrument flight segment. Commands and declarative statements were the most frequently used functions by the crews in both segments. The seven least used functions, each representing less than 5.1% of the communications, were aircraft clearance, navigational assistance, flight review, correct current error, feedback, directed toward crew chief, and uncodable. The lack of message units about aircraft clearance is a result of the simulator's inability to replicate obstacles.

All 13 functions were analyzed to determine if there were significant differences in communications due to mission segment and crewmember duties. However, there were no significant relationships with the seven least used functions. Therefore, only the results of the six most used functions are presented.

There was a significant three-way interaction between mission segment, crewmember, and these six functions, $F(12, 384) = 17.18$, $p < .01$. Post hoc analysis of the interaction indicated there were significant differences in the functions used by the two crewmembers within and across the mission segments. The differences in the communication functions

Table 9

Mean Percentage of Message Units for Each Function in Each Mission Segment

	Troop insertion (n = 17)		Instrument flight (n = 17)	
Function	PF	PNF	PF	PNF
Inquiry	15.8	5.1	13.0	5.9
Command	3.9	36.2	13.1	22.2
Declarative	37.0	30.1	33.6	30.5
Response to inquiry	5.5	5.7	5.9	6.3
Acknowledgment	26.3	6.0	16.6	6.8
Aircraft clearance	1.7	1.3	0.3	0.0
Radio transmission	1.6	3.2	4.2	18.4
Navigational assistance	0.0	0.2	0.0	0.0
Flight review	1.4	1.2	1.3	1.0
Correct current error	0.0	0.0	0.0	0.0
Feedback	1.1	4.9	1.9	2.6
Directed toward crew chief	0.5	0.5	0.2	0.2
Uncodable or irrelevant	5.1	5.1	3.5	3.1

Note. PF = pilot flying; PNF = pilot not flying.

across the mission segments are presented first. Next, the differences between the PNF and the PF within each mission segment are presented. Finally, an explanation of the differences is discussed.

Crewmember across mission segments. The PNF issued more commands and made fewer radio transmissions during the troop insertion segment than during the instrument segment. The PF issued fewer commands and made more acknowledgments during the troop insertion segment than during the instrument segment. These data indicate that the PNF provided more

direction during the troop insertion segment than during the instrument flight segment and that the PF responded accordingly by acknowledging the commands. During the instrument flight segment, the PF shared more responsibility in directing the flight.

PNF versus PF within mission segments. During the troop insertion segment, the PFs asked more questions, offered more declarative information, and issued more acknowledgements than the PNFs. The PNFs issued more commands than the PFs. The distribution of communication functions is consistent with the tasks assigned to each of the crewmembers. During terrain flight, the PF has four primary tasks: (a) maintain control of the aircraft, (b) maintain obstacle clearance, (c) notify the PNF of relevant terrain features in his field of view, and (d) follow the navigational instructions issued by the PNF. The PNFs' primary responsibilities are to stay oriented on the map and to issue guidance instructions to the PF that will maintain the aircraft on course. During the instrument flight segment, the PNF and PF issued equal percentages of declarative information but the PNF made significantly more radio transmissions than the PF. Again, this difference is consistent with the duties of the two crewmembers during instrument flight.

Explanation of function differences. The differences in functions used by the crewmembers across and within segments may be explained by two factors. First, the roles of the crewmembers are different in the segments. After transitioning to instrument flight, the crews can decrease their vigilance for obstacles and focus their attention on reviewing and discussing the approach procedure. The opportunity to exchange information about the approach procedure immediately before execution provided them with a common knowledge base from which to execute the approach. In contrast, although both crewmembers could participate in premission planning for the troop insertion segment, the PNF had most of the current, relevant navigational information and did not always update the PF. Second, instrument flight requires contact with a controller on the ground to receive instructions and the PNF typically assumed responsibility for making these transmissions. Crew coordination requirements are increased because a third party is involved who provides information critical to the safety of the flight.

Communication Content

Similar to the analyses for function, the mean percentage of message units in each content area were

analyzed for the six functions to determine if there were significant differences in communications due to mission segment and crewmember duties. A separate ANOVA was conducted for each of the six communication functions (see Table 10). With the exception of responses to inquiry, there were significant three-way interactions between mission segment, crewmember, and content area for all six functions.

Crewmembers across mission segments. The PNFs issued more commands about heading and turns during the troop insertion segment but more commands about altitude during instrument flight, $F(8, 256) = 13.88$, $p < .001$. During the troop insertion segment, the PNFs offered more information about the terrain and aircraft position while offering less information about instrument readings and pilot's intentions, $F(10, 320) = 10.49$, $p < .001$. Finally, during the troop insertion segment, the PFs asked more questions about heading and terrain features [$F(6, 192) = 15.00$, $p < .001$] and acknowledged more commands [$F(1, 32) = 11.21$, $p < .01$] than the PFs during the instrument flight segment.

These results indicate that the crews focused on different concerns in the two segments. During the troop insertion segment, the crew is focused on navigation: The PNF issues commands and provides information related to navigation and the PF seeks directional information as required. During the instrument flight segment, the crew is concerned with maintaining an appropriate altitude and analyzing instrument readings.

PNF vs. PF within mission segments. During the troop insertion segment, the PNF issued more commands about heading, altitude, turns, and anticipatory commands [$F(8, 256) = 13.88$, $p < .001$] and provided more anticipatory declaratives [$F(10, 320) = 10.49$, $p < .001$] than the PF. The PF asked more questions about heading [$F(6, 192) = 15.00$, $p < .001$], made more terrain identifications and statements of aviator intent [$F(10, 320) = 10.49$, $p < .001$], and provided more acknowledgments of commands [$F(1, 32) = 11.21$, $p < .01$] than the PNF. During the instrument flight segment, the PNF issued more commands about heading and altitude [$F(8, 256) = 13.88$, $p < .001$] and made more anticipatory declaratives [$F(10, 320) = 10.49$, $p < .001$] and instrument approach radio transmissions [$F(3, 96) = 43.5$, $p < .001$] than the PF.

Table 10

Mean Percentage of Message Units for Each Content Area in Each Mission Segment

	Troop insertion (n = 17)		Instrument flight (n = 17)	
Content	PF	PNF	PF	PNF
Inquiry				
System status	1.0	0.4	0.6	0.9
Initiate checklist	0.1	0.0	0.0	0.0
Direction	7.7	0.3	2.9	0.9
Terrain	3.2	3.1	3.0	0.1
Instrument status	0.1	0.1	0.1	0.1
Aircraft position	0.8	0.1	0.4	0.0
Other	2.9	1.0	1.7	3.9
Command				
Flight systems	1.3	0.2	0.7	0.7
Initiate checklist	0.1	0.0	0.1	0.1
Bounded direction	0.5	11.5	7.5	4.9
Altitude	0.0	1.7	1.1	4.3
Airspeed	0.1	3.1	2.0	1.5
Unbounded turn	0.4	11.1	7.1	2.6
Stop turn	0.1	3.8	2.5	0.5
Anticipatory	0.3	3.6	2.5	5.2
Other	1.0	1.0	1.1	2.4
Declarative				
Instrument status	3.6	1.9	2.6	10.0
Terrain	20.1	9.4	13.6	0.9
Anticipatory	1.0	8.2	5.7	5.6
Checklist response	0.4	0.9	0.8	0.9
Aircraft flight path	0.4	0.8	0.7	0.2
Aircraft position/flight status	1.7	4.5	3.5	0.6
Aviator intent	6.0	1.0	3.0	4.3
Systems status	1.4	1.9	1.7	4.0
Derogatory toward simulator	0.4	0.1	0.2	0.0
Direction of aviator attention	0.0	0.1	0.0	0.0
Other	2.0	1.3	1.6	3.9

Continued...

Table 10 (Continued)

Content	Troop insertion (n = 17)		Instrument flight (n = 17)	
	PF	PNF	PF	PNF
Response to inquiry				
Serves as command	1.3	0.2	1.7	0.4
Confirm/affirm	3.3	3.5	2.2	3.0
Corrective/negative	0.6	0.7	0.3	0.3
Other	0.5	1.1	2.1	2.2
Acknowledgment				
Command	18.4	0.6	9.0	2.0
Information	7.9	5.4	7.6	4.9
Radio Transmissions				
Aircraft position	1.6	0.6	1.5	0.6
Formation control	0.4	0.5	0.6	0.0
Operations control	1.2	0.4	0.2	0.1
Approach control	0.0	0.0	15.9	3.6

Note. PF = pilot flying, PNF = pilot not flying.

The communication content areas used by the crewmembers support the results of the function analysis. The distribution of communication across content areas is consistent with the tasks assigned to each crewmember. The differences in the relationship of the crewmembers' communications across mission segments are related to the changing responsibilities of the crewmembers. Therefore, the function and content percentages were used to investigate whether performance on crew tasks is related to crew communication.

Relationship of Crew Task Performance and Communication

A primary objective of this research is to determine if crew coordination, as it is reflected in the patterns of crew communication, affects mission task performance. Because effective communication patterns were not known a priori but crew performance criteria were known, the research hypotheses must be inverted. That is, instead of testing whether one communication pattern produced more effective performance

than another pattern, the data were analyzed to determine if good performers transmit different categories of information than poor performers.

Thus, Pearson product-moment correlational analyses and mixed design ANOVAs were conducted to investigate the relationship of the communication variables with performance on the three mission tasks: navigational accuracy, threat evasion, and instrument flight. Significant correlations are reported at $p < .05$. In the ANOVAs, navigational performance, threat evasion performance, instrument flight performance, and crewmember were treated as between-group factors. The dependent variable was the percentage of message units. Significant interactions were further analyzed with Tukey HSD tests.

Communication Rate and Crew Task Performance

The rate of message units was not related to performance on any of the crew tasks. This result agrees with Krumm and Farina's (1962) finding that the communication rate was not significantly correlated with simulator flight checks, hours required to solo, and navigational and bombing accuracy scores.

Communication and Navigational Accuracy

There were significant relationships between the measures of navigational accuracy and crew communication during the troop insertion segment. The length of flight was correlated with inquiries of direction ($r = .52$) and responses to inquiries that serve as a command ($r = .60$). The number of deviations was positively correlated with commands to stop turns ($r = .53$) and direction of aviator attention ($r = .49$), and negatively correlated with acknowledgements of commands ($r = -.52$). The percentage of time off course was correlated with inquiries of direction ($r = .60$), commands for unbounded turns ($r = .49$) and altitude ($r = .47$), and negatively correlated with acknowledgements of commands ($r = -.52$).

These results indicate that navigational accuracy is related to adequate planning and exchanging adequate information. Crews who made fewer navigational errors anticipated upcoming terrain cues and events that would take their attention from navigation. Also, they provided

explicit information about heading or direction and confirmed the receipt of information.

An ANOVA was used to test for differences in communication between crews rated on the basis of their percentage of time off course as good (M = 5.7%) or poor (M = 47.6%) navigators. The PFs of the good navigational crews asked fewer questions about heading or direction [$F(6, 144) = 2.65$, $p < .01$] and provided less information about terrain features, $F(10, 240) = 2.42$, $p < .01$. Apparently, the PNFs of good navigational crews were providing adequate information about heading or direction during the entire segment. The PNFs of the poor crews required assistance from the PF to identify their location by noting terrain and cultural features.

Communication difficulties appeared to exist before crews deviated from the course. When communication was examined only when crews were on course, the PFs of the poor crews asked more questions regarding heading or direction [$F(6, 144) = 2.31$, $p < .05$], indicating they were not receiving sufficient information to remain on course prior to the deviation. Thordsen, Klein, and Wolf (1991) suggested that ineffective crews failed to focus on appropriate time horizons. In this case, the PNFs were not directing their attention far enough ahead in time to provide anticipatory information to the PFs.

The communication data obtained while the crews were off course are confounded because they include all message units emitted by the crews during their deviations from course. That is, the crews were not always aware they were off course and there was insufficient information on the videotapes to determine when the crews became aware of their navigational error. Considerable time elapsed before some crews verbalized that they were off course and they generally operated as if they were still on course during these periods. Therefore, the off-course communication data could not be analyzed and interpreted.

Communication and Threat Encounters

There were six significant correlations between crew communication during the troop insertion segment and two of the threat encounter performance measures, mean and longest duration. The number of encounters and total duration of encounters were not significantly correlated with any of the communication categories. Mean duration was positively correlated with commands about altitude (r = .60) and

negatively correlated with anticipatory declaratives (r = -.53), checklist responses (r = -.50), and direction of aviator attention (r = -.48). Longest duration was positively correlated with unbounded commands to turn (r = .47) and negatively correlated with anticipatory declaratives (r = -.52).

These results indicate that both individual skills and crew coordination skills affected threat evasion performance. A lack of flying proficiency was shown by the PFs who required multiple directives to adjust their altitude. Crews who evaded the threat more successfully were more coordinated, as shown by the larger percentage of anticipatory comments, specific turn instructions, and standard checklist responses.

An ANOVA was used to test for differences between crews classified as good or poor in evading the threat. Crews were dichotomized into good or poor on the basis of the duration of their longest threat encounter. Crews with durations of 20 s or less were classified as good evaders; crews with durations of greater than 21 s were classified as poor evaders. This classification produced a significant difference between the good (M = 12.2 s) and poor (M = 29.7 s) groups, $t(17) = -4.031$, $p < .001$.

There was a significant three-way interaction between function, crewmember, and threat duration, $F(12, 408) = 2.15$, $p < .01$. Of the poor crews, the PNFs emitted less declarative information than the PFs. The PNFs of the good crews issued fewer commands than the PNFs of the poor crews. Finally, the PFs of the good crews issued more acknowledgements than the PFs of the poor crews. Apparently, the PNFs of the good crews were providing adequate information to the PFs and the PFs were acknowledging that information.

Communication and Instrument Flight

Instrument flight performance was significantly correlated with only one communication function, declarative statements (r = .59) and one content area within that function, declarative statements about instrument readings (r = .53). These correlations suggest that information specific to the task must be exchanged for the instrument approach to be executed successfully.

The crews were dichotomized into good and poor instrument approach groups on the basis of the performance

score they received for the instrument flight segment. The nine crews receiving scores of 3 or 4 were classified as good instrument flight crews and the nine crews receiving scores of 1 or 2 were classified as poor instrument flight crews. This classification produced a significant difference between the good (M = 3.6) and poor (M = 1.7) groups, $t(16) = -7.8$, $p < .0005$.

There was no significant interaction between communication categories, instrument flight performance group, and crewmember. However, the ANOVA did indicate that crews who performed well on the instrument flight segment provided more declarative information than the crews who performed poorly, $F(12, 384) = 2.68$, $p < .01$. Observation of the videotapes indicated that crews who discussed the approach procedures before execution performed better during the approach and landing.

Summary and Conclusions

This project was conducted to identify aircrew coordination requirements for Army UH-60 aircraft by investigating the relationship between crew communication and performance on crew tasks. In addition, the research was designed to identify measures of crew performance, to determine the relationship between mission type and communication, to identify communication profiles related to crew performance, and to develop training objectives for a crew coordination training program.

Methodological Limitations

The interpretation of the research results must consider the lack of information about individual pilot proficiency and differences in performance between the aircraft and simulator. First, no flight or simulator proficiency data were collected, except for measures of flight and simulator time during the aviator's career and during the preceding 6 months. The aviators were allowed to practice in the simulator during the FARP resupply segment before beginning the performance and communication measurement.

All the aviators except one were rated RL1, but the wide variation in flight and simulator time probably reflects differences in aviator skills. The lack of information about pilot proficiency prevents the identification of aviators who may not have had adequate individual skills. Variability in

the performance measures caused by a lack of individual proficiency could mask the effects of crew coordination.

Second, potential performance differences must be considered between the flight simulator and the aircraft. The simulator does not perfectly replicate the aircraft and the consequences of unsatisfactory performance are different in the aircraft and simulated environments. Although the UH60FS provides a high degree of realism, the aviators remain safe regardless of their actions. Thus, aviators may prepare less carefully and may respond more carelessly in the flight simulator than in the aircraft.

The results must also be interpreted with the preliminary intent of the investigation in mind: the acquisition of basic information about crew coordination requirements for the development of a training program. The research was conducted as an observational experiment using the UH60FS with operational unit aviators performing a typical mission scenario designed to require coordination behaviors from the crews. Other than presenting the different types of mission segments, there were no manipulations designed to test specific crew coordination hypotheses. Instead, the research was designed to collect baseline data that can be used to generate hypotheses for subsequent evaluation.

Despite these limitations, the results provide a foundation for the identification of crew coordination requirements in Army rotary wing aviation. The information obtained from this project is particularly important because of the presence of crew coordination failures in Army aviation accidents and the lack of other relevant research.

Communication and Types of Missions

The results provide conclusive evidence that the rate, topic, function, and content area of crew communications are different across and within mission segments. More message units were emitted during the troop insertion segment than the instrument segment and the PNF emitted more message units than the PF in both segments.

The differences in the function and content area for crewmembers between mission segments and between the PNF and PF within each mission segment reflect the changing informational demands and task responsibilities of the individual crewmembers during each type of mission. The differences in communication patterns across mission segments and between crewmembers within a segment are descriptive and

are not necessarily recommended for use to improve crew performance. The communication patterns reflect differences in the current crew tasks as a function of mission type rather than the optimum pattern for crew coordination. The development of crew training on the basis of the differences in crew tasks and requirements is discussed in the Recommendations section.

Performance Measures for Crew Tasks

The results demonstrate that objective mission effectiveness measures can be identified for crew tasks. The measures of navigational accuracy and threat encounters differentiated between good and poor crew performance during the troop insertion segment. Success in both terrain flight navigation and threat encounter tasks does not guarantee mission success, but failure on either task will ensure that the crew does not complete its mission.

The measure of instrument flight performance, ratings of critical aspects of the NDB approach, also discriminated between crews. More objective measures related to instrument flight were identified but not developed because there was insufficient information available to evaluate them on the videotapes. For example, the altitude and heading of the aircraft could not always be determined. This made it difficult to determine whether a crew violated altitude or airspace restrictions during the instrument flight and NDB approach.

Relationship Between Communication and Mission Effectiveness

The results indicate that some aspects of crew communication are significantly related to crew performance. The rate of communication was not related to crew performance on mission tasks. However, the use of some communication functions and content areas were significantly correlated with each measure of mission effectiveness. Navigational errors were positively related to inquiries about direction; responses to inquiries that serve as a command; commands for unbounded turns, altitude, stop turns; and statements about aviator attention. Navigational errors were negatively related to acknowledgements of commands. Two threat encounter measures, mean and longest duration of threat encounter, were positively related to altitude and unbounded turn commands; they were negatively related to anticipatory declaratives, checklist responses, and direction of aviator attention. The performance of critical tasks during the

instrument approach was positively related to declarative statements about instrument readings.

Crew Performance and Communication Profiles

The results provide some indication that the crews categorized as good and poor on measures of mission effectiveness used different patterns of communication. There was a significant interaction for all three crew performance measures that identified different communication profiles for good and poor performers. The PNF of the good navigational crews provided more information about heading or direction throughout the mission and the PNF of the poor navigational crews provided the PF with less information prior to deviating from course. The PNF of the crews who evaded the threats more successfully issued fewer commands than the PNFs of the poor crews, and the PF of the good threat crews made more acknowledgments of information than the PFs of the poor crews. Crews who performed better during the NDB approach issued more declarative information than the crews who performed poorly.

Although the results demonstrate that the profiles of communication were different for good and poor crews, they do not conclusively demonstrate that crews who replicate the communication profiles of the good crews will perform their mission tasks more effectively than crews who replicate the communication profiles of the poor crews. Because optimal communication patterns were not known before the project began, the current research examined the communication of crews categorized on the basis of performance, not crew performance as the result of communication pattern. To test the effectiveness of the good crew patterns, crews must be trained to use the communication pattern of the good crews and then compare their performance with that of a control group.

Army Aircrew Coordination Training Requirements

The results of this research project indicate the need for aircrew coordination training for Army helicopter pilots, particularly for synchronizing the actions of the PF and PNF. Improving the quality, frequency, and timing of information exchange and the acknowledgment of that information should improve aircrew performance and safety in the types of helicopter missions investigated. Poor performance in navigation, avoiding and evading enemy threats, and performing an instrument approach were all related to a lack

of relevant and timely information. The results of the ASMIS accident and incident analyses also found the quality and frequency of information exchange to be the largest contributor (41%) to crew coordination errors (Leedom, 1990).

In addition, poor or unsafe performance was observed in the simulated missions that resulted from improper workload prioritization (e.g., directing the PF's attention to a low priority task resulting in a crash). In the ASMIS data base, workload prioritization was involved in 35% of the human error accidents (Leedom, 1990). The workload prioritization errors are probably underestimated in the simulator because the limited visual field restricts the opportunity for assigning and performing aircraft clearing responsibilities.

Most of the errors that were observed during the UH60FS missions resulted from a lack of standardization in flight procedures and communication protocols between the crewmembers. This type of training is not emphasized in the available CRM and ACT programs, probably because these procedures and protocols have long been prescribed by commercial and military fixed wing standard operating procedures. At the time this research was conducted, the Army Aircrew Training Manual standards did not prescribe communication protocols and were designed primarily to assess the aviator's individual proficiency rather than the aviator's proficiency as a crewmember. In fact, there was only one task that described the requirement to perform as a crewmember; all the other tasks described individual performance (e.g., plan a VFR flight, perform preflight inspection, perform hovering flight).

The available CRM and ACT programs generally emphasize crew coordination problems in team relationships and crew climate, interpersonal skills, or in the problem solving and decision making process when the crew is required to improvise a solution to an unanticipated problem. Except for a lack of planning and crewmember assertiveness during the NDB approach, there was very little evidence of these types of problems among the UH-60 crews.

Therefore, Army aircrew coordination training requirements identified in this research can be met only partially by the available CRM and ACT programs. There are obvious differences in the aircraft (rotary wing versus fixed wing aircraft) and in the flight regime (usually high versus low altitude). Despite these differences, the few aircrew coordination programs used to train military helicopter pilots were adapted from commercial or military fixed wing programs. However, the validity of these programs for helicopter pilots has not been demonstrated beyond shifts in

self-reported attitudes (e.g., Geis, 1987) and short-term changes in accident rates that may be attributable to other factors (e.g., Alkov, 1989). More importantly, the emphasis of the available programs does not address the most apparent training need of Army aviators: improved crew synchronization by improving the quality and format of the crew's communication. Specific recommendations for an Army crew coordination program are made in the following section.

Recommendations

The results of this research were used to develop the following five specific crew coordination training recommendations. The last section presents recommendations for future research.

Use Standardized Communication Formats

The first recommendation is to train crews to issue directives and provide information to the other crewmember using standard formats. To reduce ambiguity and ensure compliance, the issue of directives should include three elements: the directive, an acknowledgement, and a confirmation. For example, when issuing a turn command, the PNF should direct the PF to turn in a specified direction; the PF should acknowledge by repeating the directive; finally, the PNF should monitor the PF to ensure that he understands and complies with the command.

Similarly, exchanging information should include two elements: a declarative statement and an acknowledgement of receipt. If the sender fails to hear the other crewmember acknowledge the statement, the sender should repeat the statement. The results support this recommendation. The acknowledgment of commands was negatively correlated to percentage of time off course and crews who were less successful in evading threat encounters issued fewer acknowledgements. Also, a failure to confirm an acknowledgment resulted in two of the five deviations from course caused by crew coordination errors.

Provide Adequate Information

Second, train crews to provide adequate information. The most important application of this recommendation is in issuing bounded turn commands during day, VMC flight. That is, the turn directive should tell the PF where to start or

stop turning. For example, the PNF may direct the PF to "turn right to the mountain at two o'clock." To allow the PF to keep his attention outside the cockpit, the boundaries used by the PNF should refer to terrain features or clock positions.

The use of rally terms such as "start turn" and "stop turn" to initiate and cease turning maneuvers was positively related to navigational errors (e.g., deviations from course, percentage of time off course) and the longest duration of threat encounter. Such directions provide minimal information to the PF concerning how far to turn. Rally terms may still be appropriate for night flight, especially using night vision devices.

Establish Task Priorities

Third, train crews to prioritize tasks within the mission and to accomplish tasks on the basis of task priority. For example, the PNF should avoid directions that require the PF to look inside the cockpit. One crew flew into the ground because the PNF directed the PF to check the time, which required the PF to look inside the cockpit. The priority tasks of the PF are to maintain aircraft control and ensure obstacle clearance by focusing attention outside the cockpit. Crews must know how to recognize which tasks are important, particularly in dynamic environments such as helicopter flight, and to neglect low priority tasks when they detract from the essential tasks.

Maintain an Optimal Time Horizon

Fourth, train crews to expand their time horizon during terrain flight navigation. The PNF must provide anticipatory information to ensure the PF is aware of upcoming terrain or cultural features and of his flight and communication requirements in the near future. Crews who provided more anticipatory statements had shorter threat encounter durations. As shown in the communications during the troop insertion segment, information presented too early may overload the PF and information presented too late may cause the PF to ask continually for additional data. As Thordsen, Klein, and Wolf (1991) indicated, the optimal time horizon may vary depending on the terrain, the route of flight, and the individual crewmembers.

Improve Crew Planning

The final training recommendation is to emphasize thorough planning, preferably before the mission begins but also during the mission. Much of the coordination between crewmembers is accomplished prior to beginning the mission in the aircraft. The high time stress and lethality present in the Army rotary wing flight regime require that contingencies be predicted and corresponding responses preplanned. This environment often does not provide sufficient time to explore alternatives or to problem solve. Crews should develop courses of action during premission planning sessions.

Planning sessions provide crews with opportunities to produce mental images of the terrain through which they will fly and of other aspects of the mission. Through these mental simulations, the crew can predict where problems might occur and determine how each crewmember should respond. Although the premission planning of the crews was not analyzed in this research, many of the individual errors that occurred might have been avoided by more thorough planning. In addition, the results from the instrument flight segment showed that crews were more likely to complete the segment successfully when both crewmembers reviewed the NDB approach and discussed relevant requirements and contingencies (e.g., missed approach procedures). The mission briefing included a warning about deteriorating weather conditions, so part of the instrument approach should have been planned before the flight began. Nonetheless, the crews who used the available flight time to review the plan performed better during the approach.

Future Research

The final recommendation is for continued research to examine crew coordination requirements in the Army's tactical rotary wing aircraft. Because of the observational nature of the current research, the results should be verified through experimentation with trained and control groups. For example, crews trained to exhibit the communication pattern of the crews who performed mission tasks effectively could be compared to crews with no specific communication training. Any extension of the present investigation should also include a night scenario, preferably using night vision devices to determine if different crew coordination requirements are associated with the night environment.

In addition, future research should include other aircraft, such as the Army's AH-1 and AH-64. Crew tasks that

involve operating the weapon systems and the tandem seating arrangement of these aircraft may produce unique crew coordination requirements. An analysis of the CH-47, which has a larger crew, may identify additional crew coordination requirements and techniques.

Finally, investigations of crew coordination in operational aircraft are recommended to verify the relevance of the simulator findings to the operational environment. Although the UH60FS is a high fidelity simulator, some behaviors (e.g., frequent aircraft clearance requirements) and motivators (e.g., safety) that occur in the aircraft may not be adequately represented in the simulator environment. Such behaviors and motivators may alter the crew coordination requirements within the operational environment from those identified in the simulator.

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APPENDIX A

AIR MISSION BRIEFING

OPORD References: Map Sheet 2317 II

Weather:

Ceiling: 1000	VIS: 1.5 miles	Winds: 310/10	Max Temp: +23
Dew Point: +20		Spread: 3	EENT: 2030
Max PA: +500			
SR: 0600	SS: 0600	BMNT: +23	Max DA: +1000
MR: 2130	MS: 0600	% Illum: 20	

Weather Warnings and Advisories:

Low ceilings and decreasing visibility throughout day

Task Organization:

TF 4/101:

a. A/4-101

b. TM/PFDR

1. SITUATION

   a. Enemy Forces

      1. Infantry/Armor Forces: BDE VIC VK91 71
      2. Artillery: Unk.
      3. ADA Forces: Vic VK96 75; Vic VK92 71; Vic VK86 77; Vic VK98 75
      4. Air Support: Unk.

   b. Friendly Forces

      1. Inf. Bde: 2nd Inf. Bde. Vic VK10 51
      2. TF 3-327 Vic WK1245 5152
      3. ATK/CAV: NA

   c. Attachments and Detachments

      1. Team Alpha Pathfinders

2. MISSION

a. Pick up blivits at assembly area GRAPE (WK0641 5552). Resupply 2 blivits to jump FARP APPLE (VK9175 6335) and return to GRAPE.

b. Conduct air assault with TF 3-327 to destroy retrans site Vic VK88 80 (Objective CARLA) and return to jump FARP APPLE to refuel and lager. Be prepared to conduct an extraction ops. of security forces from FARP APPLE to return to ISB ORANGE (WK1245 5152).

3. EXECUTION

a. Commander's Intent: Conduct operation with speed, surprise, and precision.

b. Concept of operation: This is a priority mission. The first mission is to establish a jump FARP to support a subsequent cross-FLOT air assault operation. The second mission is a five aircraft air assault to destroy a retrans site.

c. Maneuver

1. Aircraft by type: 5 UH-60A
2. Routes (corridors): As posted
3. Objective: CARLA Vic VK88 80
4. Times: TBA

d. Fires

1. FA Unit/Type: NA
2. Priority of fires: NA
3. SEAD Information: NA
4. Close air support: NA
   ATK/CAV: NA
   Battle Positions: NA

e. Sub-unit Instructions

1. Crews, duties, freqs., call signs: See attachment
2. Commo/line up/takeoff times: +40 min./+45 min./+47 min.

f. Staging Plan

	PZ1 (GRAPE)	PZ2 (APPLE)
1. PZ Locations	WK0641 5552	VK9175 6335
2. PZ Times	TBA	TBA
3. Routes to PZ	NA (Starting Point)	via posted corridors
4. PZ Markings	Inverted Y	None
5. Formation/Dire.	Trail/360°	Stag. Left/055°
6. ACL/Cargo/Weight	NA/blivits/7000	11/packs/NA

7. ATK/CAV Coordination: NA
8. Sling load procedures: SOP
9. Light signals (beacon): SOP
10. Spare Aircraft Procedures: SOP
11. Special Mission Equip.: SOP

g. Air Movement Plan

1. Route: SP 1 (JOSEPHINE) = WK055 588, ACP 1 = WK035 686, ACP 2 = WK029 745, ACP 3 = WK013 785, RP 1 (CAROLYN) = VK897 785
2. Report crossing Josephine
3. Penetration Points: Cross FLOT at WK031 735
4. Enroute formation/Rotor separation/Angle: Stag. Left/3-5/30-45.
5. Enroute airspeed: Enroute as required to make +63 min. H-Hour
6. Deception measures: NA
7. ATK/CAV Mission: NA
8. Abort Criteria: One Aircraft
9. Air Movement Table: NA
10. Threat Breakup Procedures: SOP
11. Door Guns: Out at FLOT
12. Cargo Doors: Open

13. External Lighting: Form. = NA, Position = SOP, Anti-Col. = SOP

14. Crew position: NA

15. Lead change procedures: SOP

16. Formation exit procedures: SOP

17. Lost contact/In-flight join-up: SOP

18. Downed aircraft procedures: SOP

19. DAARP/SAR Plan: SOP

20. SERE Plan: SOP

21. SEAD Plan: NA

h. Landing Plan

	LZ1	LZ2 (P)	LZ2 (A)
1. LZ Name:	APPLE	KING	JOKER
2. LZ Location	VK91756335	VK87757970	VK87708085
3. LZ Time	TBA	+63 min.	+63 min.
4. Form./Dir.	Single/050°	Trail/350°	Trail/330°
5. LZ Markings	None	None	None
6. LZ Control	None	Call Inbnd Z69/44.00	Call Inbnd Z69/44.00

7. ATK/CAV Mission: NA

8. Go arounds: Flight = Left; Single Ship = Left

i. Laager Plan

1. Location: FARP APPLE

2. Type: Fly

3. Time: NA

4. Security Plan: M60D

5. Scatter Plan: SOP

6. Call Forward Plan: NA

j. Extraction Plan: NA

k. Return Air Movement Plan

1. Route: SP 2 (FILLY) = VK883 788, ACP 4 = VK875 698, RP 2 (STALLION) = VK890 650

2. Report crossing Filly and Stallion

3. Penetration Point = Cross FLOT at VK874 667

4. Enroute Formation/Airspeed = Free Cruise Right/80 knots

5. ATK/CAV Mission: NA

6. Threat Breakup Procedures: SOP

7. Door Guns: In at FLOT

8. LZ Location: APPLE

9. Ldg. Formation/Direction: Trail/055°

10. LZ Markings/Control: None/None

l. Coordination Instructions

1. MOPP Level/NBC Threat: NA

2. Friendly ADA Status: IFF = Yellow Tight/Off 1 km prior to FLOT

3. Lost Commo.: SOP

4. NVG Specific Procedures: NA

5. VHIRP/IMC: Base altitude = 2500, Airfield = Harris, Freq: See approach plate

COMMUNICATIONS CARD

Call Sign	PC	PI	Aircraft	Duties
W41	Ownship	Ownship	749	Lead/Navigation
W23	TBA	TBA	811	Flt. Follow
W17	TBA	TBA	212	AMC
W65	TBA	TBA	694	Flt. Follow
W09	TBA	TBA	580	Trail

Internal Frequencies: FM1 = 32.25 VHF = 122.7 UHF = 242.6
Battalion TOC: Freq. = 40.40 Call Sign = A21
Commander = W06

AMC = W17

A P P E N D I X   B

COMMUNICATION CONTENT AREAS

1. INQUIRY

11. System status: A message unit concerning the status of a flight system (e.g., "Is the doppler working?"; "Which frequency is fox mike?").

12. Initiate checklist: A message unit that serves to initiate the accomplishment of a checklist (e.g., "Is the before takeoff check done?").

13. Heading or direction: A message unit about the heading or direction of the aircraft; the question may refer to the current heading or to the direction appropriate in the future (e.g., "Did you say 049 or 349?"; "When I get to the river, should I take the right or left fork?").

14. Terrain features: A message unit concerning the identification of terrain or cultural features on the ground (e.g., "Is that a river or a pond?").

15. Instrument reading: A message unit about readings from any instrument available to the crew including clocks or watches (e.g., "What's our altitude?"; "How much time has elapsed?").

16. Aircraft position: An inquiry that refers to the location of the aircraft (e.g., "How far is it to the release point?").

17. Other: An inquiry that does not fit into another content area.

2. COMMAND

21. Flight systems: A message unit to make adjustments to a flight system or instrument (e.g., "Tune the FM radio to 44.40."; "Turn up the next checkpoint on the doppler.").

22. Initiate checklist: A message unit to initiate a checklist (e.g., "Give me the before takeoff check.").

23. Bounded heading or direction: A message unit to fly in a specific direction or heading (e.g., "Turn to 350°."; "Turn to three o'clock."; "Fly over that bend in the road.").

24. Altitude: A message unit to adjust or maintain the altitude of the aircraft (e.g., "Get lower.").

25. Airspeed: A message unit to adjust or maintain the airspeed of the aircraft (e.g., "You need to speed up a bit.").

26. Unbounded turn: A message unit to initiate or continue a turn without an indication of which heading or direction to terminate the turn (e.g., "Turn right."; "Keep turning.").

27. Stop turn: A message unit to terminate a turn on the current heading or direction (e.g., "Stop turn."; "Roll out here.").

28. Anticipatory: A message unit to initiate or terminate an activity in the future (e.g., "When you come up on the NDB, do a parallel approach.").

29. Other: A message unit that does not fit into another category (e.g., "Okay, go ahead and take the controls.").

3. DECLARATIVE

30. Instrument reading: A message unit that reports information presented on an aircraft instrument (e.g., "Airspeed is 110."; "Stabilator is full down.").

31. Terrain identification: A message unit that contains information about the identification of features in the data base (e.g., "I have a hill at 11 o'clock."; "We are crossing a road.").

32. Anticipatory: A message unit that reviews or notifies what the crew will see or do in the future (e.g., "In about 3 Ks you will see a mountain off of the nose.").

33. Checklist response: A message unit indicating that items of a checklist have been completed (e.g., "Tail wheel locked, brakes released, good in the rear.").

34. Aircraft flight path: A message unit indicating the course of the aircraft (e.g., "Okay, we're going to the alternate LZ.").

35. Aircraft position/flight status: A message unit that reports the location of the aircraft or the amount of time remaining until an event occurs (e.g., "We're about 5 miles out of the LZ."; "We got 4 minutes until we gotta land.").

36. Aviator intent: A message unit made by the PF indicating the control inputs he/she is making (e.g., "Coming left."; "I'm slowing down now.").

37. System status: A message unit concerning the state of a flight system (e.g., "Now the Doppler's working again.").

38. Derogatory toward simulator: A negative message unit about the simulator (e.g., "This thing sure is flying slow today.").

39. Direction of aviator attention: A message unit that indicates a change in the focus of a crewmember's concentration (e.g., "I'm coming inside.").

40. Other: A message unit that does not fit into another content area (e.g., "And the visibility's getting worse.").

4. RESPONSE TO INQUIRY

41. Serves as a command: A message unit in response to a question that serves as a directive (e.g., "What heading?"; "Come to 180.").

42. Confirm/affirm: A positive message unit in response to a question (e.g., "Yes, it is 190.").

43. Corrective/negative: A message unit indicating disagreement with the question (e.g., "No, it's not the stabilator.").

44. Other: A message unit that provides information beyond either affirming or negating a previous question (e.g., "Well, I had 6 in the doppler for this.").

5. ACKNOWLEDGMENT

51. Command: A message unit indicating the receipt of a directive (e.g., "Okay, 220.").

52. Information. A message unit indicating the receipt of data (e.g., "Roger, I know.").

6. CLEARANCE

61. Request/direct: A message unit asking for a crewmember to determine if the aircraft is clear of obstacles; takes priority over inquiries and commands to the crew chief (e.g., "Clear me down, crew chief.").

62. Clears aircraft: A message unit indicating the aircraft is clear of obstacles or warning of inadequate clearance; takes priority over inquiries and commands to the crew chief (e.g., "Clear left."; "Watch that tree.").

7. RADIO CALL

71. Aircraft position: A message unit made over the radio to report aircraft position (e.g., "W41 is Josephine.").

72. Formation control: A message unit made over the radio to control the multiaircraft formation (e.g., "Whiskey flight, formation breakup.").

73. Operations control: A message unit made over the radio that pertains to the crew's mission (e.g., "After refuel, we will line up in trail formation for extraction mission.").

74. Approach control: A message unit made over the radio that pertains specifically to instrument flight (e.g., "Roger, 23749 is inadvertent IMC approximately 7 K south of Apple.").

8. NAVIGATION ASSISTANCE

81. Request: A message unit that indicates the crew is disoriented or lost and needs assistance from a source outside of the crew (e.g., "W23, W41 is stumble."; "W41 requests grid square ").

82. Helping response: A message unit to provide navigation assistance made by a source outside the crew (e.g., "Roger, that grid is 00077159."; "If you continue your right turn, we'll be south of the FARP.").

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